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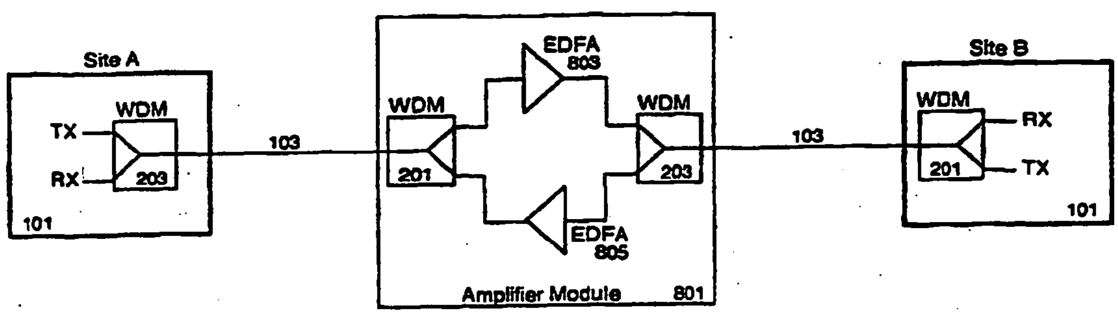

(57) Abstract

A device in accordance with the invention uses erbium-doped optical amplifiers (EDFA), wave division multiplexers (WDM) and optical isolators to implement a dual wavelength bidirectional (single fiber) optical amplifier module. The amplifier module advantageously allows communication network managers to increase fiber utilization while simultaneously reducing the cost of signal amplification hardware across a fiber optic network, and simplifies field installation and maintenance. Using a novel configuration of conventional components, a system in accordance with the invention utilizes EDFAs to provide bidirectional signal amplification in the 1550 nanometer optical fiber transmission window. One embodiment of the invention uses two EDFAs to provide amplification of the (bidirectional) signal wavelengths. Signals are coupled in and out of a conventional single-mode fiber via WDM filters. In another embodiment, a single EDFA is used to amplify both (bidirectional) transmission signals. By providing bidirectional amplification through a single optical fiber, a system in accordance with the invention can advantageously reduce by half the strands of fiber cable needed to establish a link between two communication sites.

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BIDIRECTIONAL OPTICAL AMPLIFIER

The invention relates to the amplification and transmission of signals through optical fibers. The invention makes use of erbium-doped optical fiber amplifiers, wavelength division multiplexers, and optical isolators to provide a single-module amplifier suitable for bidirectional communications through a single optical fiber.

Conventional Two-Fiber Transmission

Figure 1 depicts a conventional baseline two-fiber transmission link where block 101 represents either a regeneration or central office site. Connecting the two sites together is a fiber optic cable 103. Within the cable there are multiple strands of fiber, of which two have been shown. In this type of transmission system, communication from a transmitter (TX) at site A to a receiver (RX) at site B utilizes one signal wavelength (λ_1) and one strand of an optical cable. Communication in the opposite direction uses a different strand of the optical cable and the same, or different, wavelength (λ_2) to carry the signal.

Referring again to Figure 1, elements A and B (blocks 101) can represent different site configurations. In one configuration, one terminal site might communicate directly to another terminal site in a complete end-to-end, communication system. Alternatively, Figure 1 could represent a single link in a longer chain of transmission stations. In other words, sites A and B might be

representative of a site C and a site D and a site E and so on, until a final site containing terminating transmission equipment is reached.

Depending upon the wavelength chosen for transmission, the optical fiber 103 used may exhibit different attenuation characteristics which may limit the possible spacings of regenerator sites, e.g., sites A and B. Attenuation in a typical single-mode optic fiber is 0.35 db/kilometer at 1310 nm and 0.25 db/kilometer at 1550 nm. Thus, regenerator sites could be spaced anywhere from 35 to 45 kilometers when operating at 1310 nm and into the 70 to 80 kilometer range when operating at 1510 nm.

Narrow-Band Wavelength Division Multiplexing

Figure 2 depicts a conventional narrow-band wavelength division multiplexing communication system. Here, the term "narrow-band" is used to mean that more than one wavelength is utilized within the same transmission "window" of the optical fiber. For example, if the depicted system is operating within the 1550 nm window, two signalling wavelengths of 1533 and 1557 nm might be used.

Unlike the configuration shown in Figure 1, communication between site A and site B in Figure 2 is provided by a single strand of optical fiber. Bidirectional transmission is achieved through the utilization of wavelength division multiplexing (WDM) filters, 201 and 203. (The devices 201 and 203 can be the same or slightly different devices, depending upon the manufacturing technique used to create them.) The purpose of WDM filters is to couple multiple wavelengths into (hereafter referred to as 'on') and out of (hereafter referred to as 'off') the transmission fiber 103. In the example shown, WDM filters 201 and 203 couple the two wavelengths 1557 and 1533 nm on and off a single fiber 103.

The advantages of using WDM technology in the 1550 nm transmission window include: 1) WDM devices reduce, by half, the strands of fiber cable needed to establish a communication link, 2) conventional optical fibers introduce less signal attenuation per unit length at these wavelengths, allowing longer distances between regenerator sites and thereby lowering the cost of building a network, and 3) EDFA devices, which currently function only in the 1550 nm window, allow the potential for increased regenerator spacings. (EDFA technology is discussed in more detail below in conjunction with Figure 4).

Figure 3 is a variation of the system shown in Figure 1, a two-fiber design where one wavelength (λ_1) is transmitted on one fiber in one direction, and another (or possibly the same) wavelength (λ_2) is transmitted on the other fiber in the opposite direction. EDFAs can be deployed along such a link in multiple locations: immediately following the transmitter (TX), making them post-amplifiers; immediately preceding a receiver (RX), making them pre-amplifiers; or between a transmitter and receiver, as shown in Figure 3, making them line-amplifiers. In the line-amplifier configuration, regenerator spacing can be almost doubled, from approximately 70 to 80 kilometers to approximately 140 to 160 kilometers. (This analysis assumes transmission is attenuation limited, not dispersion limited). Hence, the two EDFA's 301 and 303 can be used to reduce equipment deployment costs when constructing a transmission network such as that shown in Figure 3.

Erbium-Doped Fiber Amplifier (EDFA) Technology

Figure 4 shows a conventional design for an EDFA such as that shown in Figure 3, blocks 301 and 303. In a typical dual-pumped amplifier there are either two or three optical isolators 401, two WDM filters 405 and 411, two laser pump sources 403 and 409, and a length of erbium-doped single mode fiber 407. If the amplifier is single-pumped, one of the pump sources 403 or 409 is removed. If a pump source is removed, its corresponding WDM filter is likewise removed: if

pump source 403 is removed, WDM filter 405 is also removed; if pump source 409 is removed, WDM filter 411 is also removed.

WDM filters perform the function of coupling the pump source laser wavelength into the erbium-doped fiber. Pump energy is used to elevate the erbium ions concentrated in the erbium-doped fiber to a higher-than-normal energy level. These ions will stay excited until they decay on their own accord or are stimulated to decay by the arrival of a signal wavelength photon coming in from the transmission link 103.

Isolators function as one-way conduits for optical signals. In other words, isolator elements 401 allow an optical signal to pass in a single direction, e.g., from left to right, but not from right to left.

Consider the case where a signal photon enters the amplifier of Figure 4 at the point labelled IN. The photon passes through isolator 401 and enters the WDM filter 405, where it is routed into the length of erbium-doped fiber 407. Both during and preceding the arrival of the signal photon, laser pumps 403 and 409 have been providing energy to the erbium-doped fiber via the WDMs 405 and 411, exciting the fiber's erbium ions. Upon entering the erbium fiber, the signal photon will cause decay of some of the excited erbium ions, releasing their energy in the form of (stimulated) photons. The original signal photon plus the stimulated photons then pass out of the WDM 411, through the output isolator 401, and back onto the transmission fiber 103.

It is possible, in a dual-pump configuration, to add a third optical isolator in the middle of the erbium-doped fiber 407 — dividing the erbium-doped fiber into two distinguishable lengths, one to the left and one to the right of the isolator. The purpose of this additional isolator is to provide isolation between the two pump sources so that pump source 403 cannot interfere with pump source 409. The function of isolators at the input and output of the amplifier is to eliminate

back-reflections. Thus, light reflected back against the direction of signal propagation toward the amplifier, will not get amplified.

Several aspects of amplifier design and utilization are well-known to those of ordinary skill. Of great importance in network applications is the configuration of the optical amplifier. If optical isolators are used internal to the amplifier, then they make the amplifier an inherently unidirectional device. In Figure 4 for example, the isolators 401 prevent a signal from propagating from right-to-left (OUT toward IN). Another characteristic that must be considered when deploying an amplifier is what signal wavelength to use in conjunction with the amplifier's pump(s) wavelength. Because amplifier gain is not perfectly flat for all incoming wavelengths (different wavelengths exhibit different gain characteristics), the precise wavelengths to use are a function of the gain variations of the different pump wavelengths.

Some Conventional EDFA Based Systems

Two conventional communication links utilizing both WDMs and EDFAs are shown in Figures 5 and 6. In Figure 5 a single-fiber transmission link is shown with one EDFA 301 configured as a line amplifier. As previously stated, if the EDFA 301 of Figure 5 were a typical amplifier (built as described in Figure 4 for example) this communication link would not provide bidirectional transmission; transmission would occur from site A to site B, but not from site B to site A. (It is possible to build an optical amplifier by removing the optical isolators but this creates inherent instability problems that make it difficult to maintain a safe operating environment and is, therefore, not recommended by existing industry standards).

In Figure 6 EDFA amplifiers 301 are deployed as post-amplifiers, immediately following the transmitters (TX) and immediately before the WDM filters 201 and 203. It is possible to obtain bidirectional transmission over the

single fiber link 103 in this configuration. There are, however, at least two disadvantages to this implementation. First, in this design the high power signal leaving a transmitter is physically collocated with an optical receiver (RX). In such cases, care must be taken to avoid near-end optical loop backs. In other words, at site A 101 with a high power signal leaving EDFA 301, any signal reflection from the WDM filter 203 could return to site A's receiver and cause an optical feedback problem. The same is true of site B's configuration. Another drawback to this configuration is in the economics of deploying post amplifiers versus line amplifiers. (Line amplifiers provide a larger gain margin than do post amplifiers). If line amplifiers could be used to extend the distance between sites, while maintaining the ability to provide bidirectional transmission, the cost of the resulting system's amplifier hardware could be significantly reduced.

Conventional unidirectional amplifier systems (e.g., Figure 3) use two fibers per link; one fiber carrying data in one direction and the other fiber carrying data in the opposite direction. If two signal channels are needed in such a system, four fibers are required. Likewise, conventional bidirectional amplifier systems (e.g., Figure 2) use one fiber per link. If two signal channels are needed in such a system, two fibers are required. The reduction in fiber count of a bidirectional WDM design could also be achieved in a unidirectional WDM design by employing multiple transmitters on a single fiber in one direction and multiple transmitters on a single fiber in the opposite direction. An example of the latter system design, using two transmitters and two receivers at each site, is depicted in Figure 7. In this design, transmitter one (TX_1) and transmitter two (TX_2), located at site A 701 and operating at wavelength 1 and wavelength 2 respectively, are coupled onto a single fiber 103 through the WDM filter 203. Both of these wavelengths are amplified by the EDFA 301 during signal transmission. Receivers one (RX_1) and two (RX_2), located at site B 703, distinguish between the two wavelengths — each acquiring one of the two arriving wavelength signals.

The design of Figure 7 could be built using conventional EDFAs, including internal isolators, because only unidirectional transmission through the amplifiers are required. The primary disadvantage of this design lies in the difficulty of protecting such a system. With multiple systems on a single fiber, if that fiber is lost due to a cable cut or some other disaster, then multiple systems would be down at the same time. By convention, transmission systems employ a 1-by-N protection scheme, meaning that one backup system is used to protect multiple (N) transmission channels. If a single channel fails, that channel's traffic is rerouted to the backup channel and no traffic is lost. The failed channel is said to have been "switched to protect." In a 1-by-N scheme if multiple systems (transmitters or receivers) fail, only one system can switch to protect. In order to protect the configuration shown in Figure 7, multiple protect systems would be required, since there are multiple systems on a single fiber. This is a costly endeavor and one which the invention addresses.

Economic Disadvantages of Current Embodiments

The conventional systems shown in Figures 1 through 7 illustrate what is believed to be a trend in the current thinking in fiber optic art. Most system configurations shown at symposiums and in technical journals appears to be presented from the point of view of a manufacturer of amplifiers, wherein the presenters are anxious to show the flexibility of an amplifier and what its maximum potential is. While this narrow, component-focused, approach may well help advance the state of the art in component design, it does little to address the big-picture problems faced by communication network managers, namely those associated with network design. In short, the conventional systems illustrated in Figures 1 through 7 are seen as showing that the field of designing and building fiber optic amplifiers (and other fiber optic components useful in a fiber optic network) is distinctly different from the field of designing, building, and maintaining a fiber optic network per se.

Further, those publications that do address communication link design appear to be concerned primarily with building ultra-long distance links, e.g., transoceanic links. In these applications the designers have the luxury of being able to construct a facility that will have the exact transmission properties required for their communications system. They can select fiber that has the correct dispersion and attenuation characteristics so that when the system is constructed, e.g., to form a single 10,000 kilometer link, error-free transmission is achieved.

The invention addresses three major constraints in the field of communication network design: 1) There already exists a fiber optic network that was built using old technology (i.e., from the early 1980s), 2) It would be prohibitively expensive to scrap the existing network and build a new network; and 3) The link distances over which signal transmission is desired is from terminal-to-terminal in most of the major cities across the United States of America. A primary concern is the cost of implementing any new design.

A device in accordance with the invention uses erbium-doped fiber amplifiers EDFAs), couplers, wavelength specific filters, optical isolators, and narrow bandwidth signalling to implement a dual wavelength bidirectional (single fiber) optical amplifier module. The amplifier module advantageously allows communication network managers to increase fiber utilization while simultaneously reducing the cost of signal amplification hardware across a fiber optic network.

Using a novel configuration of conventional components, a system in accordance with the invention utilizes EDFAs to provide bidirectional signal amplification in the 1550 nanometer optical fiber transmission window. One embodiment of the invention uses two EDFAs to provide amplification of the (bidirectional) signal wavelengths. Signals are coupled in and out of a conventional single-mode fiber via wavelength division multiplexer (WDM) filters. In another embodiment, a single EDFA is used to amplify both (bidirectional) transmission signals.

By providing bidirectional amplification through a single optical fiber, a system in accordance with the invention can advantageously reduce by half the amount of fiber cable needed to establish a link between two communication sites. Additionally, when used in a line amplifier configuration, a system in accordance with the invention can extend the distance between two communication sites.

Figure 1 through Figure 7 are block-diagram representations of some conventional fiber optic communication systems as discussed in more detail above.

Figure 8 is a block diagram representation of a system in accordance with the invention, a single-module amplifier for bidirectional transmission employing wave-division multiplexing and erbium-doped fiber amplifier technology.

Figure 9 is an expanded block-diagram representation of one possible implementation of the invention.

Figure 10 is an expanded block-diagram representation of another possible implementation of the invention.

Figure 11 is an expanded block-diagram representation of a third possible implementation of the invention.

One illustrative embodiment of the invention is described below as it might be implemented using WDM and EDFA technology. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual implementation (as in any hardware development project), numerous implementation-specific decisions must be made to achieve the developers' specific goals and subgoals, such as compliance with system- and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless

be a routine undertaking of device engineering for those of ordinary skill having the benefit of this disclosure.

Overview of Amplifier Module

Figure 8 depicts one configuration for a dual wavelength, bidirectional narrow-band WDM optical amplifier module, 801. The components used to construct the amplifier module 801 include: two WDMs (input and output ports of the amplifier module) and two EDFAs which can be either single-pumped or dual-pumped depending upon the communication system's power constraints/requirements. This line-amplifier configuration extends the regenerator spacing while providing bidirectional transmission utilizing a single-fiber strand of the cable facility 103.

It should be noted that the amplifier module 801 can be cascaded to extend even farther the distance between site A and site B. (The number of amplifiers that can be cascaded, between sites A and B, is limited by the dispersion characteristics of the transmission equipment deployed at sites A and B.)

Two problems addressed by the amplifier module 801 are the requirement for bidirectional transmission through a single fiber with minimum-cost components and the need for a flexibility of design to accommodate multiple transmission wavelengths. One major obstacle in trying to deploy EDFA technology in non-standard configurations is the gain-versus-wavelength dependence of erbium-doped fiber amplifiers. Depending upon the signal wavelength, an EDFA will exhibit different gain and noise properties. When multiple wavelengths are attempted to be used in conjunction with a single EDFA, how those particular wavelengths perform gain-wise and noise-wise has a significant impact on the (communication) system performance as a whole.

An expanded view of the bidirectional amplifier module 801 is shown in Figure 9. Suggested technical specifications for one embodiment of the invention depicted in Figure 9 are given in Table 1. To begin, assume an input signal enters the amplifier from the left, at the WDM 901. In one embodiment of the invention, WDM 901 passes the high wavelength signal of the 1550 nm window onto the upper fiber link 903. For instance, if 1533 nm and 1557 nm are the chosen wavelengths for this amplifier, the high wavelength 1557 nm is input at the common port 103 of the WDM 901. Element 901 is a dichroic WDM which also provides output isolation of the optical signal. The signal then passes through the upper fiber link 903 to a 95-5% optical splitter 905 where the 5% tap leads to an optical detector 907 for input power measurements, and 95% of the input signal passes through the splitter and on through the optical isolator 909. The purpose of the optical detector 907 is to monitor input signal power and provide alarm capability in the event that a fiber should become cut or a connection broken. This, in turn, provides operational (field) personnel with knowledge of how the communication system is performing.

In this embodiment, amplification of the high wavelength input signal is provided by the 980 nm pump source 911. Lasertron Corporation in Burlingame, Massachusetts is one supplier of 980 nm optical pumps with reliability suitable for long-haul telecommunication applications. This pump wavelength was chosen in coordination with the signal wavelength of 1557 nm. A 980 nm pump source's optical spectrum has an inherently higher gain and, hence, higher noise in the lower 1550 nm window wavelengths. This makes a 980 nm pump source a good choice to use in conjunction with a high wavelength input signal; amplification can be achieved in the higher transmission window wavelengths (slightly less than the peak gain) while allowing the noise at lower wavelengths to be filtered out. Similar characteristics can be achieved at other pump wavelengths by varying design parameters of the erbium-doped fiber.

Table 1. Suggested Component Specifications

Block	Item	Specification
901	Narrowband Wavelength Division Multiplexor	dichroic filter technology passband: 1553 ± 3 nm insertion loss: < 1.5 dB isolation: > 35 dB backreflection: < -40 dB polarization stability: < 0.2 dB
903	Optical Fiber	single-mode fiber such as Corning SMF-28 glass or equivalent
905	Optical Power Splitter	fused biconic paper technology 95% passed / 5% tapped operating range: 1550 ± 30 nm
907	Photodetector & Circuitry	germanium or indium-gallium-arsenide technology, optimized for maximum sensitivity at low levels, e.g., -35 dB operating range: 1550 ± 30 nm
909	Optical Isolator	Faraday rotator technology operating range: 1550 ± 30 nm insertion loss: < 1.5 dB isolation: > 40 dB backreflection: < -45 dB polarization stability: < 0.2 dB
911, 913, 915	980 nm Single-Pump EDFA (Copropagation or counterpropagating)	operating range: 1530 - 1565 nm saturated output power: > 12 dB small signal gain: > 20 dB noise figure: < 6 dB polarization stability: < 0.3 dB MTBF: > 14,000 hours
917	Fiber Splice	interface between erbium-doped and standard single-mode optical fiber
919	Narrowband Wavelength Division Multiplexor	same as component 901 except, passband: 1557 ± 3 nm
921	Optical Power Splitter	same as component 905
923	Photodetector & Circuitry	same as component 907
925, 927, 915	1440 nm Single-Pump EDFA	same as components 911, 913, and 915

In tandem with the input signal, the pump signal passes through the WDM filter 913 and into the erbium-doped fiber 915. Output from the erbium-doped fiber — the amplified input signal — is then spliced back into a conventional single-mode fiber 903 at the splice point 917. The amplified input signal then passes through the WDM filter 919 and out onto the cable facility 103. Like WDM 901, element 919 is a dichroic WDM which also provides output isolation of the optical signal. The purpose of the output WDM 919 is two-fold. First, it couples, or combines, input and output light at the output of the amplifier. Secondly, it provides noise filtering of any amplified spontaneous emission that is present in the 980 nm pumped EDFA.

As shown in Figure 9, a low wavelength input signal (1533 nm in the present example) enters from the right through the WDM 919. In a manner similar to that discussed for the high wavelength input signal, the low wavelength input signal is routed to the lower leg via the WDM 919 where the signal passes through the 95-5% optical coupler 921; 5% of the light is bled off for input power readings and 95% passes through to the optical isolator 909. As in the high wavelength signal leg, the optical detector 921 is used to monitor input signal power and provide alarm capability in the event that a fiber should become cut or a connection broken.

The optical pump 925 used in this leg of the amplifier operates at 1480 nm. (Numerous manufacturers supply 1480 nm optical pumps, e.g., British Telcom and DuPont). A 1480 nm pump has almost the exact opposite characteristics as a 980 nm pump — its peak gain and noise contributions are in the high 1550 nm window wavelengths. Thus, the low wavelength input signal is amplified while the noise at higher wavelengths can be filtered out. Similar characteristics can be achieved at other pump wavelengths by varying design parameters of the erbium-doped fiber. In tandem with the low wavelength input signal, the pump signal passes through the WDM filter 927 and into the erbium-doped fiber 915. Output from the erbium-doped fiber — the amplified input signal — is then spliced into a conventional single-mode fiber 903 at the splice point 917. The amplified input signal then passes through the WDM 901 and out onto the cable facility 103. The purpose of the output WDM 901

is essentially identical to the output WDM 919. That is, to combine input and output light at the output of the amplifier and to bandpass traversing signals (noise filtering).

Optical splitters 905 and 921 are included for monitoring and alarm purposes only and are not functionally significant to the invention. Splitter elements 905 and 921 could be removed without affecting the operation of the invention. Similarly, additional optical splitters could be included to provide additional signal monitoring and alarm capabilities.

One advantage of the example amplifier module shown in Figure 9 is that each signal wavelength passes through its own amplifier gain path. Some of the prior-art designs shown in Figures 1 through 7 demonstrate multiple wavelengths passing through a single amplifier. In most multiwavelength amplifier designs, gain competition between different signal wavelengths is a problem. For instance, if a particular signal wavelength disappears, the question of how the amplifier's gain is distributed amongst the remaining wavelengths must be addressed. All of these issues are advantageously avoided in the amplifier design of Figure 9 because each signal wavelength is amplified by its own amplifier.

The WDM (bandpass) filter 901 is conventionally referred to as a "west" WDM, and the WDM (bandpass) filter 919 as the "east" WDM filter. In a similar manner, the EDFA 803 — shown in block 801 — is conventionally referred to as a "west-to-east" EDFA and the EDFA 805 as an "east-to-west" EDFA.

Generic Amplifier Module

Figure 10 depicts a generic configuration of Figure 9's amplifier module in which optical couplers have been substituted for specific wavelength division multiplexer components. Blocks 1001 and 1005 represent fiber optic couplers, similar to the 95-5% splitters/couplers used in Figure 9 for optical power detection. While any splitting configuration is acceptable (e.g., 50-50% or 95-5%), the choice

of splitting ratio will affect the amplifier performance. EDFA blocks 301 and 303 remain the same as in previous drawings.

Bandpass filter (BPF) 1003 is a specific dichroic filter, designed to pass the chosen wavelength (λ_1) in the amplifier module's upper path — through EDFA 301. Functionality, the BPF 1003 is identical to a WDM. (Physically, the BPF is a two-port device whereas a WDM is a three-port device.)

BPF 1007 uses the same technology as the BPF 1003, except that the passband of the filter is now centered about a second wavelength (λ_2) — optimized for amplification by EDFA 303.

Single-Amplifier Embodiment

Figure 11 depicts another embodiment of the invention that can be constructed utilizing a single EDFA. In this configuration, bidirectional transmission over a single optical fiber is achieved using four WDM filters. All signal wavelengths must pass unidirectionally through the EDFA 301 due to the presence of the optical isolators in the EDFA 301. Therefore, the two transmission wavelengths must be broken apart and recombined through WDM filters. Similarly, the two reception wavelengths must be broken apart and recombined through WDM filters. WDM filter 203 is constructed to bandpass 1557 nm and WDM filter 201 is constructed to bandpass 1553 nm.

Going through Figure 11 in a left-to-right direction, a 1557 nm signal is transmitted from site A 101, through the east WDM filter 203, and onto the fiber cable 103. As the signal enters the amplifier module it is separated by the west WDM filter 201. (Each WDM filter in Figure 11 has its external connection points labeled either 33 or 57. Connections labeled 33 carry optical signals at the 1533 nm wavelength. Connections labeled 57 carry optical signals at the 1557 nm wavelength.) The signal then travels to the east WDM filter 203 where it is routed

into the EDFA amplifier 301. Upon leaving the EDFA, the 1557 nm signal is routed by another west WDM filter 201 to the amplifier output east WDM filter 203 where it is placed onto the fiber optic transmission cable 103. Finally, the signal leaves the transmission cable 103, enters the west WDM filter 201 at site B 101, and is routed to that site's receiver equipment. Signals transmitted from site B, at 1533 nm, take a different path through the WDM filters 201 and 203 on their way to site A's receiver.

An advantage of this embodiment over the configuration described in Figure 8 is that only a single erbium-doped fiber amplifier is required. Because multiple wavelengths are being amplified by a single amplifier, it is sometimes preferable that the EDFA 301 in Figure 11 use a dual-pump amplifier rather than a single-pump amplifier. The additional gain provided by a dual-pumped EDFA could compensate for the signal strength lost by virtue of passing it through a number of additional elements.

* * *

It will be appreciated by those of ordinary skill having the benefit of this disclosure that numerous variations from the foregoing illustration will be possible without departing from the inventive concept described herein. Accordingly, it is the claims set forth below, and not merely the foregoing illustration, which are intended to define the exclusive rights claimed in this application program.

CLAIMS:

1. An optical line amplifier comprising:

(1) a west coupler configured to link a west light path with

(a) a west-to-east (WTE) amplifier and at least one WTE filter following the WTE amplifier, said at least one WTE filter being configured to pass signals having a wavelength λ_1, and

(b) an east-to-west (ETW) amplifier and at least one ETW filter following the ETW amplifier, said at least one ETW filter being configured to pass signals having a wavelength λ_2; and

(2) an east coupler configured to link an east light path with (1) the WTE amplifier and the at least one WTE filter, and (2) the ETW amplifier and the at least one ETW filter.

2. The optical line amplifier of claim 1, wherein the west coupler and at least one of the WTE filters form respective parts of a west wavelength division multiplexer filter.

3. The optical line amplifier of claim 1, wherein the east coupler and at least one of the ETW filters form respective parts of an east wavelength division multiplexer filter.

4. The optical line amplifier of claim 1, further comprising at least one WTE filter preceding the WTE amplifier.

5. The optical line amplifier of claim 1, further comprising at least one ETW filter preceding the ETW amplifier.

6. The optical line amplifier of claim 2, wherein at least one of the WTE amplifier and the ETW amplifier is an erbium-doped fiber amplifier.

7. The optical line amplifier of claim 2, wherein the wavelength λ_1 is not equal to the wavelength λ_2.

8. The optical line amplifier of claim 2, wherein one of λ_1 or λ_2 is 1553 nanometer and the other of λ_1 or λ_2 is 1557 nanometer.

9. An optical line amplifier comprising:

(1) a west wavelength division multiplexer filter configured to link a west optical fiber with

(a) a west-to-east (WTE) erbium-doped fiber amplifier configured to pass signals having a wavelength λ_1, and

(b) an east-to-west (ETW) erbium-doped fiber amplifier configured to pass signals having a wavelength λ_2, where λ_1, does not equal λ_2; and

(2) an east wavelength division multiplexer configured to link an east optical fiber with (1) the WTE erbium-doped fiber amplifier and (2) the ETW erbium-doped fiber amplifier.

10. A method of transmitting a west-to-east (WTE) optical signal that is propagating in a first direction, referred to as a WTE direction, in a light conductor in which an east-to-west (ETW) optical signal is propagating in a second direction, referred to as an ETW direction, comprising the steps of:

(1) diverting the WTE optical signal to an amplifier;

(2) amplifying the WTE optical signal; and

(3) re-transmitting the WTE signal in the WTE direction in the light conductor.

11. The method of claim 10, wherein the light conductor is an optical fiber.

12. A method of propagating a first optical signal, referred to as a west-to-east (WTE) signal, comprising the steps of:

(1) transmitting the WTE signal in a first direction, referred to as a WTE direction, in a light conductor in which an east-to-west optical signal referred to as an ETW signal, is propagating in a second direction, referred to as an ETW direction;

(2) diverting the WTE optical signal to an amplifier;

(3) amplifying the WTE optical signal; and

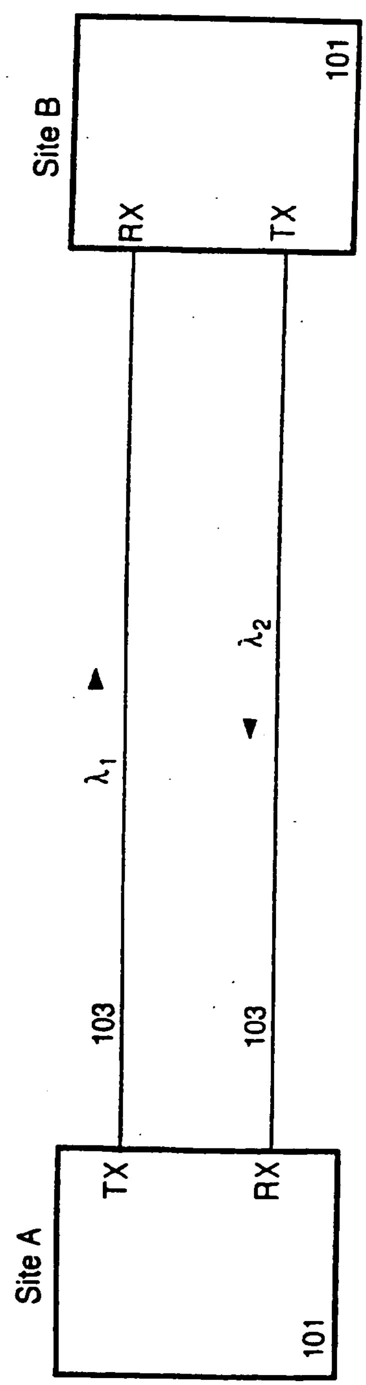
(4) re-transmitting the WTE signal in the WTE direction in the light conductor.

13. An optical line amplifier comprising:

(1) a west wavelength division multiplexer filter configured to link a west light path with an amplifier module; and

(2) an east wavelength division multiplexer filter configured to link an east light path with the amplifier module, wherein the amplifier module is configured to amplify both the east light path and the west light path unidirectionally through a single erbium-doper fiber amplifier.

Figure 1
(Prior Art)



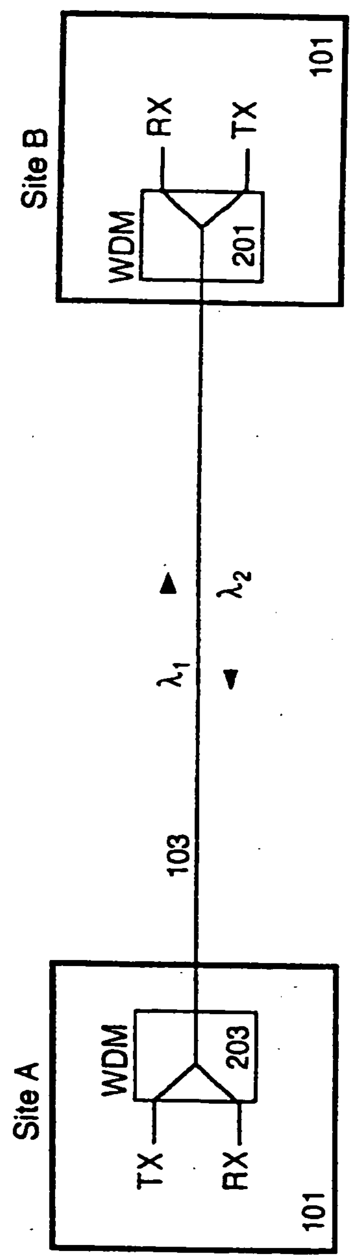
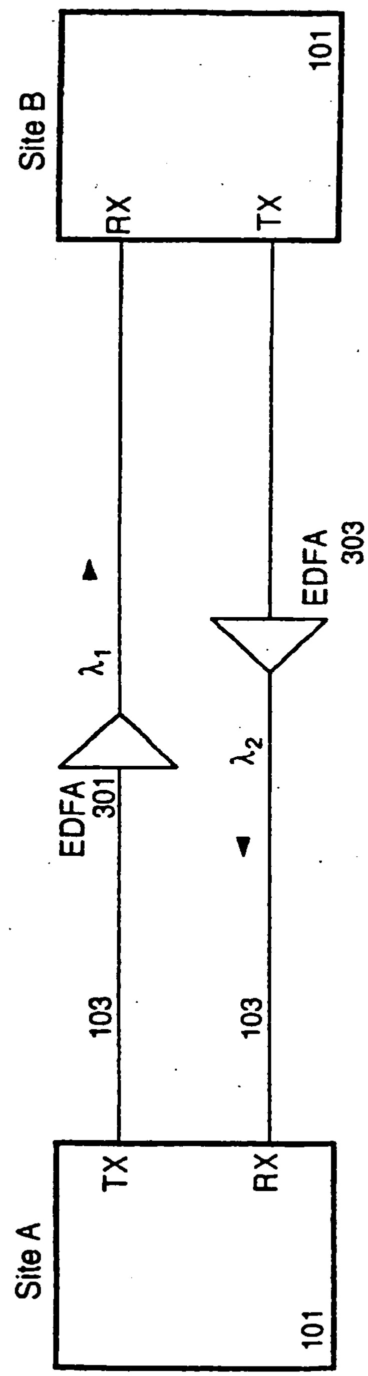


Figure 2
(Prior Art)

Figure 3
(Prior Art)



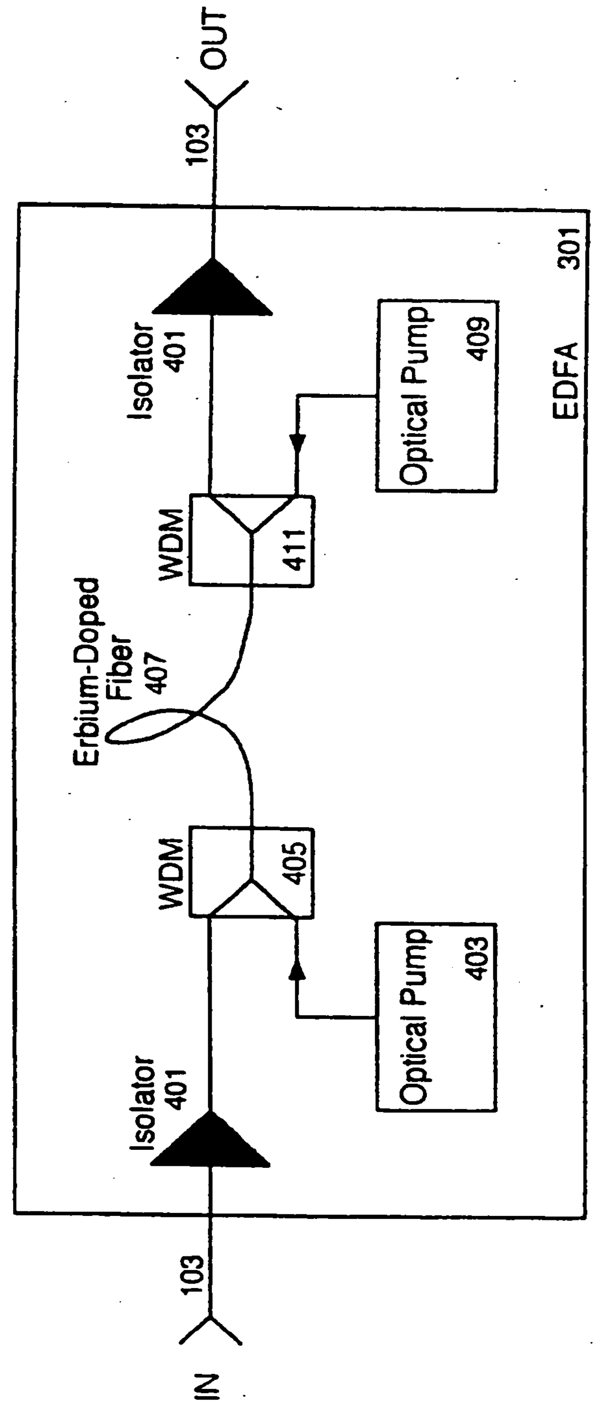
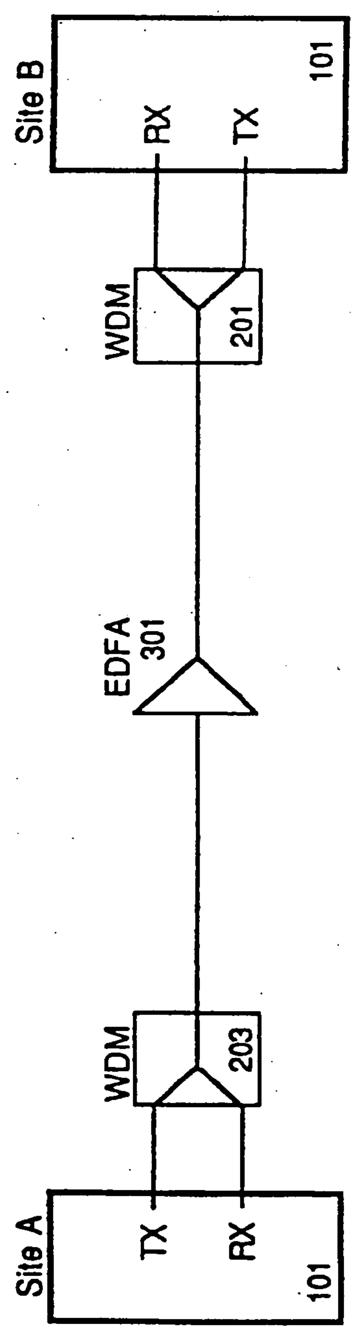


Figure 4
(Prior Art)

Figure 5
(Prior Art)



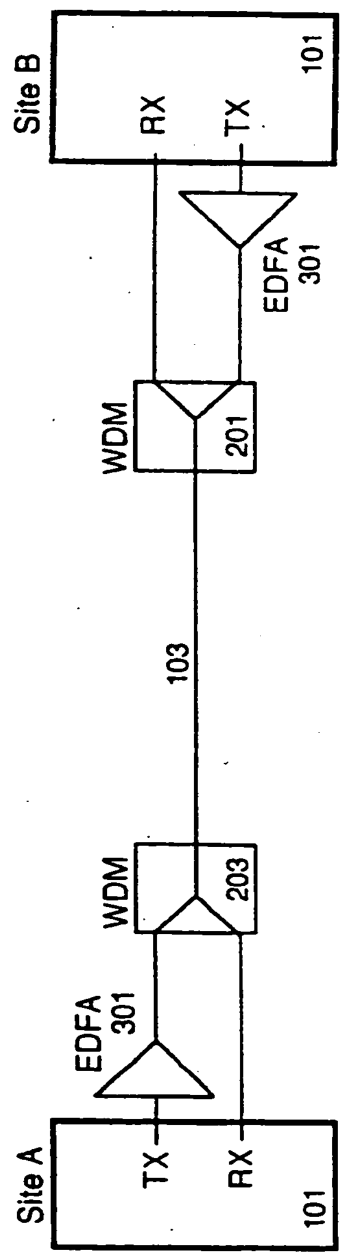


Figure 6
(Prior Art)

Figure 7
(Prior Art)

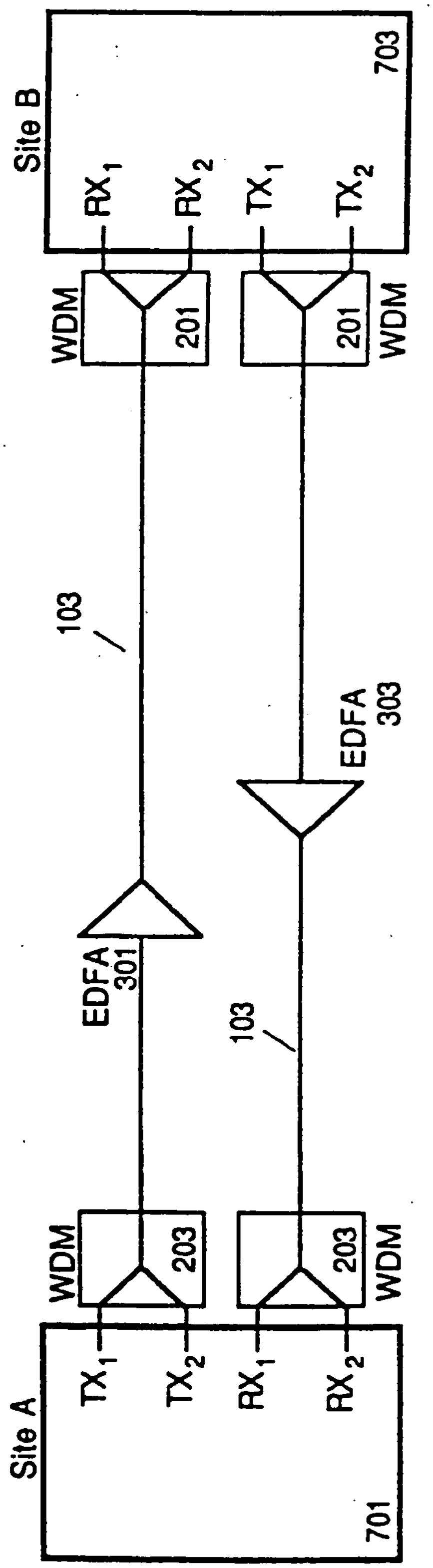
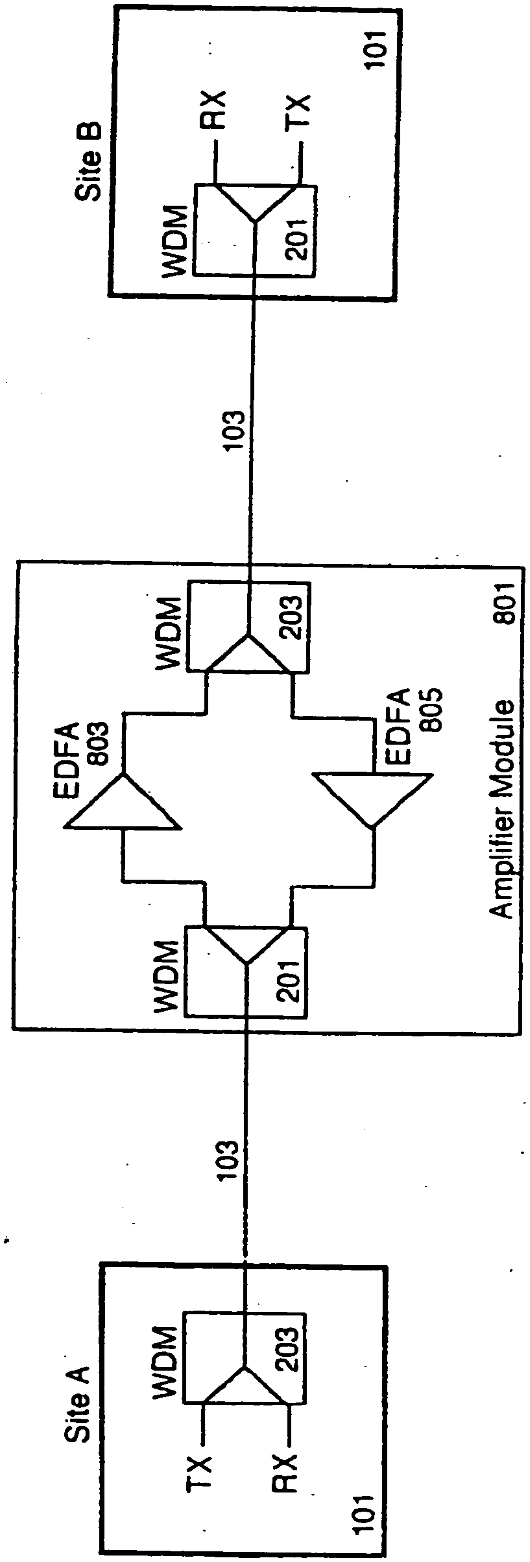


Figure 8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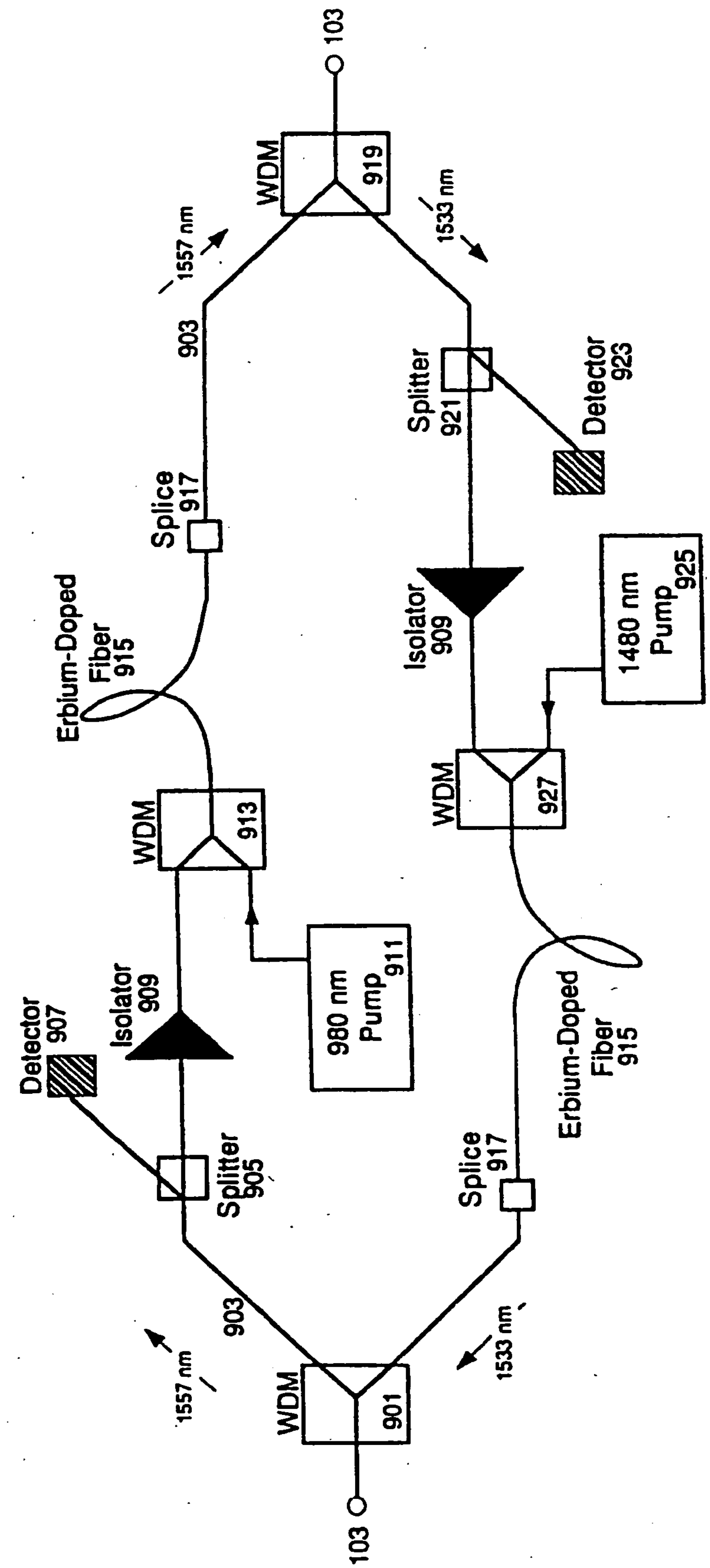
RX
TX
201
101
103
WDM
203
EDFA
803
EDFA
805
801
Amplifier Module
WDM
201
103
Site A
WDM
203
TX
RX
101

Figure 9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Fiber
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Isolator
909
1480 nm
Pump 925
WDM
913
WDM
927
980 nm
Pump 911
Detector
907
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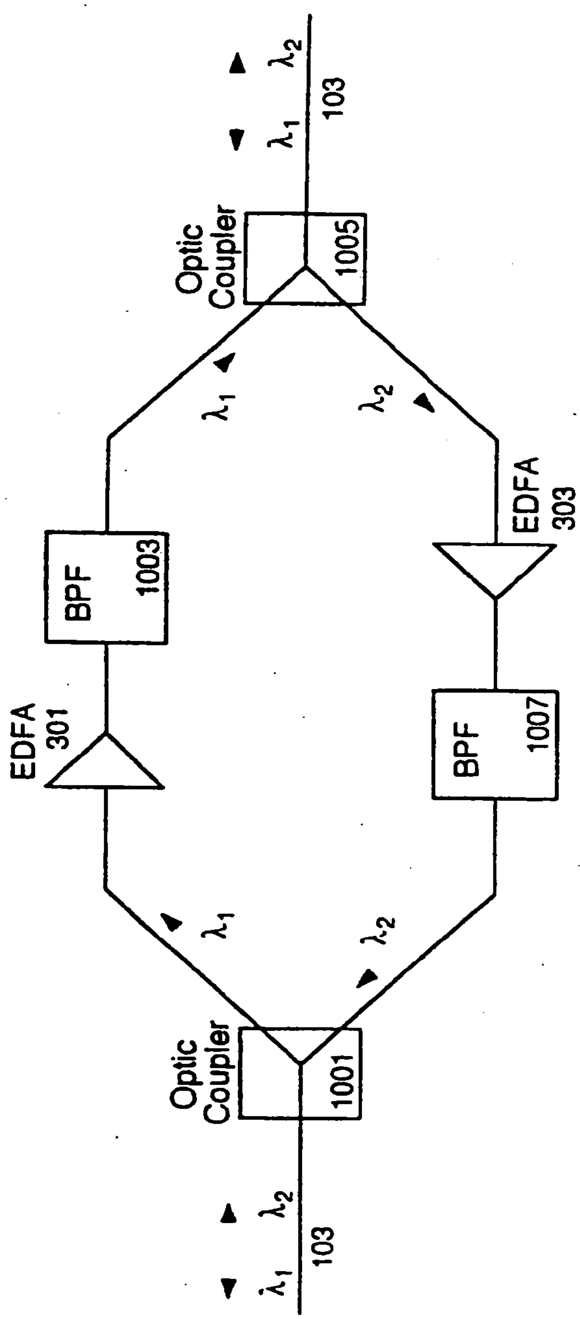
WDM
901
103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λ2
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Optic Coupler
1005
λ1
λ2
BPF
1003
EDFA
301
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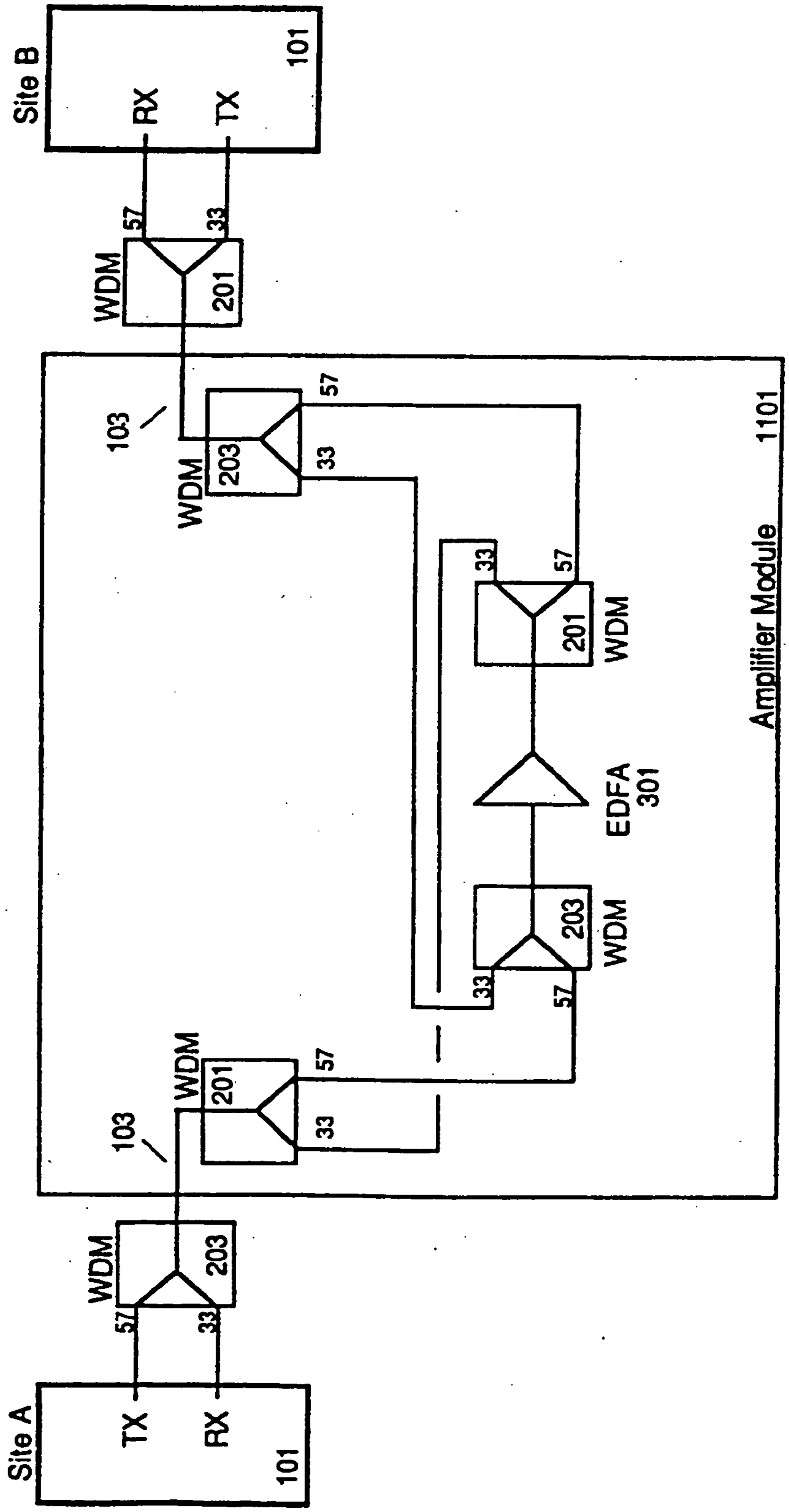
303
BPF
1007
λ1
λ2
Optic Coupler
1001
λ1
λ2
103

Figure 10

Figure 11


Site B
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TX
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WDM
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WDM
203
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Amplifier Module
EDFA
301
WDM
203
33
57
WDM
201
57
33
103
WDM
203
57
33
Site A
TX
RX
101

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 94/13697

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B10/16 H04B10/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	IEEE PHOTONICS TECHNOLOGY LETTERS, vol.4, no.8, August 1992, NEW YORK US pages 911 - 913 BARNARD ET AL 'Bidirectional fibre amplifiers' see page 911, right column, line 32 - line 37 see page 912, left column, line 22 - line 26 see page 912, left column, line 32 - line 34 see figure 1	1-3,6-8
Y		4,5

X	PATENT ABSTRACTS OF JAPAN vol. 16, no. 188 (E-1198) 1992 & JP,A,04 023 628 (NEC) see abstract	9

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[X] Further documents are listed in the continuation of box C.

[ ] Patent family members are listed in annex.

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"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
3 March 1995	06.04.95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Williams, M.I.

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ELECTRONICS LETTERS, vol.29, no.14, 8 July 1993, STEVENAGE GB pages 1268 - 1270 SEIKAI ET AL 'Novel optical circuit suitable for wavelength division bidirectional optical amplification' see page 1268, right column, line 9 - line 16 see page 1268, right column, line 20 - line 27 see page 1269, left column, line 9 - line 11 see figure 1	10-13
Y		4,5

1